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GRIT BLASTING A DISTRIBUTED ROUGHNESS BASED ON A 30% PROBABILITY OF EXCEEDENCE

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The objective of this study was to obtain a prescribed roughness on a metal surface through control of grit blasting techniques. It includes a description of the equipment used to grit blast the metal samples, the grit-blasting technique, the photomicrographic technique, and the procedure used to characterize the roughness. As a result, calibration curves were obtained which gave surface roughness as a function of grit blasting pressure setting, grit size, and surface material.

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FOREWORD

This report documents a surface roughness study conducted at the Naval Surface Weapons Center/White Oak (NSWC/WO) in February 1981. The objective of the study was to obtain a prescribed roughness on a metal surface through control of a grit-blasting technique. The grit-blasting technique was used to generate a desired surface roughness height and distribution on wind tunnel models.

The report includes a description of the equipment used to grit blast the metal samples, the grit-blasting technique, and the photomicrographic technique used to record the surface roughness. It also outlines the procedure used to characterize the roughness. Calibration curves for the grit-blasting apparatus located in the Aerodynamics Model Shop (Bldg. 402-117) were obtained which give surface roughness as a function of grit-blasting pressure setting, grit size, and surface material.

This work was performed in support of the Maneuvering Thermodynamics and Shape Change Technology Program conducted by AVCO Systems Division, Wilmington, Massachusetts in the NSWC/WO Tunnel 8 (WTR 1346). A special thanks is expressed to F. W. Rider (R32) for preparing and photomicrographing the metal samples.

Approved by:

C.A. Fisher

C. A. FISHER

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INTRODUCTION

Surface roughness is used on wind tunnel models for a number of reasons. First, it is commonly used as a boundary layer trip to produce turbulent flow over models which are tested at low Reynolds number conditions. Secondly, it is used to generate aerothermodynamic effects such as augmented heat transfer or skin friction. In each case, the exact character of the roughness must be known in order to compare results from different tests and facilities.

The current study centers on a grit-blasted roughness and its characterization. Grit-blasting parameters under study included:

1. supply pressure to the grit-blasting apparatus

2. size of grit used

3. type of metal being roughened

The above parameters were varied (see Table 1) and the resulting surface roughness characterized using a photomicrographic technique and statistical analysis based on a 30% probability of exceedence. Both the characterization and the photomicrographic techniques are outlined in this report. The results of this study will make it possible to obtain a prescribed surface roughness by controlling grit-blasting techniques on the grit-blasting apparatus located in the Aerodynamics Model Shop (Bldg. 402-117).

GRIT BLASTING EQUIPMENT AND TECHNIQUE

The grit-blasting equipment used for this study was a commercially available sandblasting gun distributed by Montgomery Ward (model 6352) that had been converted to a grit-blasting gun. This included fitting the gun with a siphon feed and a larger nozzle (3/8" inside diameter). The nozzle size was increased to allow free passage of the larger grit. The gun was used with a maximum pressure of 120psi. The pressure was controlled through a regulator valve that could be read to $\pm$ 1psi.

The grit sizes used were #12 chilled iron grit and #20 silicon dioxide grit. The #12 grit had an average size of 56 mils and was nonuniform in shape. The #20 grit had an average size of 39 mils and also was nonuniform in shape (see Figure 1). After grit blasting a 1-inch-diameter sample for more than 3 minutes, it was noticed that the #20 grit started to break down into a powder. It was felt that this happened because the #20 grit was a nonmetallic grit.

Metal test samples used in this study were cut from 1-inch-diameter stock with a 0.10-inch thickness and a #32 finish before grit blasting. A metal holder (see Figure 2) was used to hold the samples during the blasting process. The holder supported the sample so that it would not become domed from grit blasting and shielded an area of surface which was later used as a smooth reference edge. The nozzle of the gun was held perpendicular to the sample at a distance of 2 to 5 inches during grit blasting. Samples were exposed to the blasting for a period of time which was sufficient to provide uniform and complete coverage as determined by visual inspection. It was found that roughness uniformity did not improve after a finite grit-blasting time (typically 2 to 3 minutes per square inch). Prolonged grit-blasting produced no mass loss, but simply resulted in a redistribution of the surface roughness.

PHOTOMICROGRAPHIC TECHNIQUE

The photomicrographics were produced at NSWC/WO by the Metallic Materials Branch, R32. First the roughened sample was cross sectioned using a diamond edge blade. Then half of the sample was encased in an acrylic plastic (see Figure 2). The sample was set in a form mold and the plastic allowed to harden without applying any pressure or heat.

The edge of the sample was finished by sanding with progressively finer abrasives. The process was started with 180-grit sandpaper on a belt sander. The next sandpaper used was 240-grit with the sample being moved across the sandpaper by hand. This polishing process was continued using progressively finer sandpaper, including 320-, 400-, and 600-grit. Finally, the sample was polished with 6-micron and 1-micron diamond paste on a sanding wheel.

The photomicrographs of a sectioned sample were taken using a Metaligraph with #52 Polariod film. Pictures were taken at 50X or 100X, depending on the surface roughness. After each picture, the sample was moved for the next picture while being careful to overlap the preceeding edge. A complete set of photographs were taken for each surface and the edges of the photographs were matched to form a continuous strip of photomicrographs. Figure 3 shows a portion of a continuous strip of photomicrographs at a 50X magnification.

ROUGHNESS CHARACTERIZATION TECHNIQUE

There are many different ways to define surface roughness. Values can be based on average peak-to-valley, root mean squared (overall and height only), or significant peak-to-valley dimensions. The surface roughness value obtained from these different methods vary (see Table 2) and depend on whether a profilometer or photomicrographic technique was used. The photomicrographic technique was chosen as the more accurate method of measuring surface roughness in this study because of mechanical limitations exhibited by profilometers.

Each photomicrograph was characterized by first drawing an arbitrary reference line (y_o) on the photomicrograph. This line is chosen to be representative of the "valley" locations. The y_o line should be drawn parallel to the shielded (i.e., smooth) portion of the sample and generally a few millimeters below the original surface.

Once the y_o line is drawn, height measurements are obtained at even divisions along the reference line. There should be enough divisions so as to result in 100 to 200 data points for statistical analysis. The distance between the y_o line and the surface of the sample (y) is measured at each division using a Bausch-Lomb 7x magnifer with graduated scales.

The $y-y_o$ values are plotted in histogram form and a probability of exceedence vs. $y-y_o$ curve is generated. This curve is generated by calculating the percent of the total data that exceeds the value of a certain roughness size group. From this curve, a least squares fit straight line between the 0.1 and 0.9 probability points is calculated. Then, using the slope of this line, a straight line is drawn tangent to the curve at the 0.5 probability point. The y value at the intersection of this tangent line and a probability of exceedence value equal to 1.0 produces a y correction value, h_o (see Figures A-1a and A-1b).

With this h_o value, a new reference line, called the optically apparent surface, is drawn. Now only 'significant peaks' are measured from the new reference line. 'Significant peaks' are the roughness elements which are primarily responsible for triggering transitional flow. Again, a table of $h-h_o$ values are obtained and a histogram and a probability of exceedence curve are generated (see Figures A-1c and A-1d). Both of these are done in the same manner as outlined for the $y-y_o$ data. From this probability of exceedence vs. $h-h_o$ curve, the y-value where the probability of exceedence is equal to 0.3 (h_{30}) is determined to be the roughness value for the sample. Since the plane of measurement does not pass through the middle of each peak, the h_{30} value is multiplied by a shape factor of $4/\pi$ (hemispherical shaped elements) to arrive at the final K_{30} value. Figure 4 summarizes this roughness characterization technique.

RESULTS AND CONCLUSIONS

Calibration curves for the grit-blasting apparatus were obtained for #12 grit and #20 grit and are shown in Figures 5 and 6. Three types of metal (stainless steel 17-4 PH annealed, stainless steel 17-4 PH heat treated to 1150°F, and nickel 200 annealed) were grit blasted at various pressure settings. The mechanical properties of stainless steel 17-4 PH annealed and heat treated to 1150°F were essentially the same (see Table 3) and no noticeable differences were noted in the calibration curves. For a given pressure setting, a larger roughness value was obtained on the nickel samples.

Over the range of pressure settings that were tested (20psi to 100psi), nearly linear correlations resulted. However, it is felt that there is a threshold pressure above which the sample must be grit blasted before a surface roughness can be measured. Additionally, there is a maximum pressure above which no increase in surface roughness will be found.

The error associated with reading the photomicrographs is inversely proportional to the magnification of the pictures. Error sources included resolution of the photomicrographs, reading the seven-power calibrated eye-piece, and data reduction procedures. These items are addressed in the Appendix. Using the error sources, an error bound was calculated depending on the magnification factor. The error bounds are $\pm$ 0.6 mils and $\pm$ 0.3 mils for 50X and 100X magnification respectively.

The trends that are seen make it possible to obtain a prescribed surface roughness by using the calibration curves. These curves are intended as a guide, and with the results of future roughness characterizations, the curves will become more accurate. For now, these curves will give a good approximation as to what pressure setting and grit size will be needed to obtain a prescribed surface roughness.

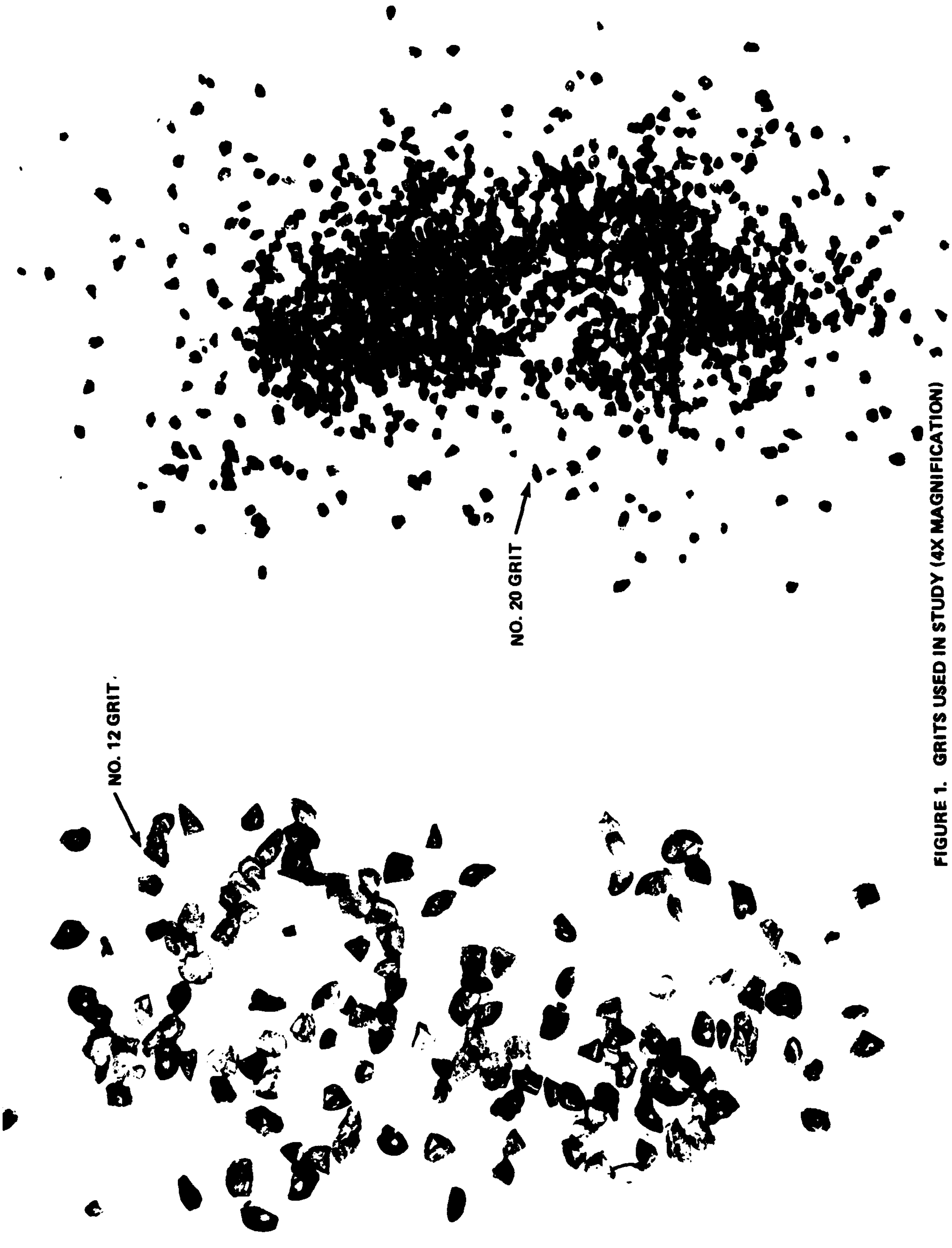


FIGURE 1. GRITS USED IN STUDY (4X MAGNIFICATION)

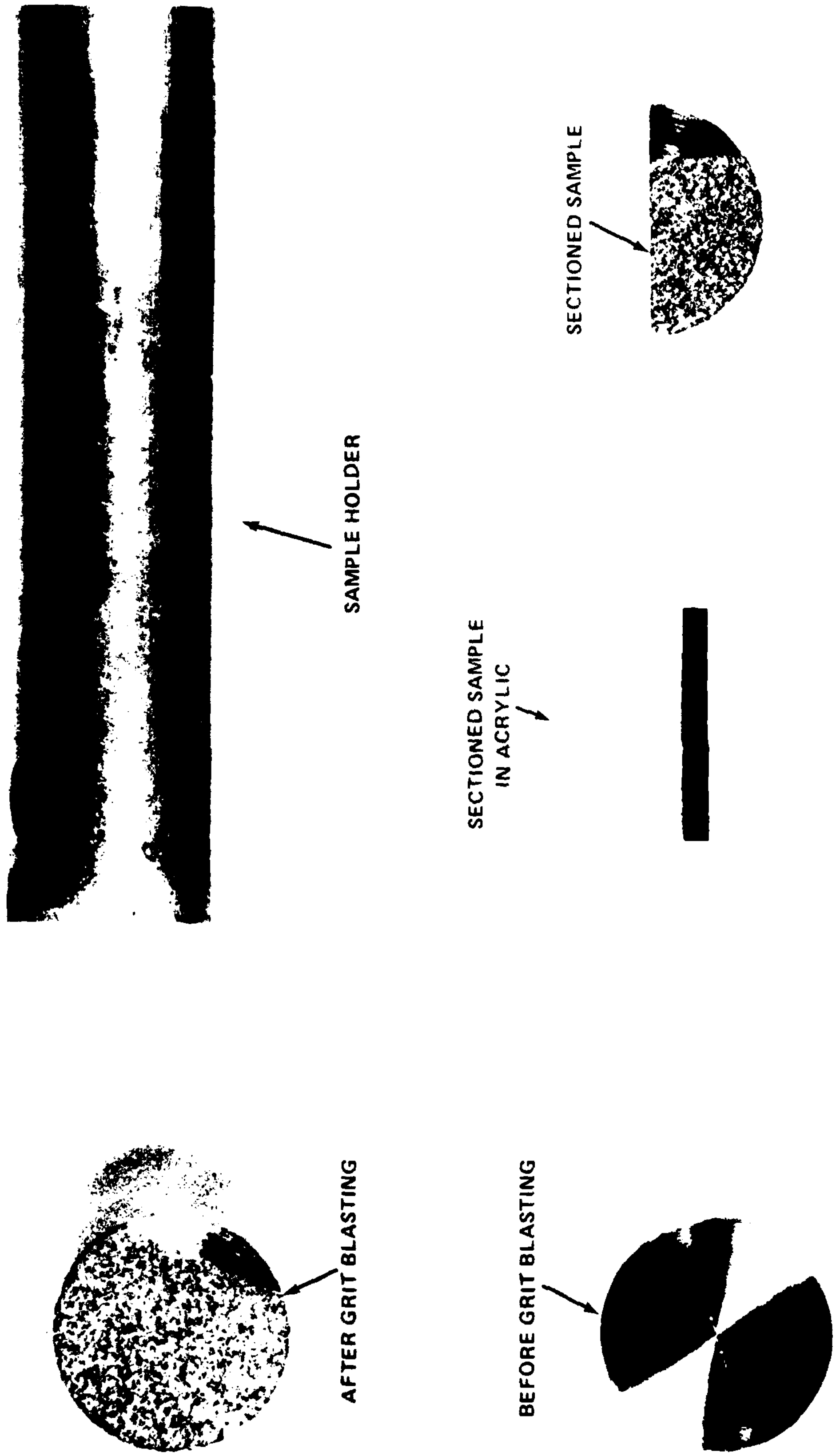
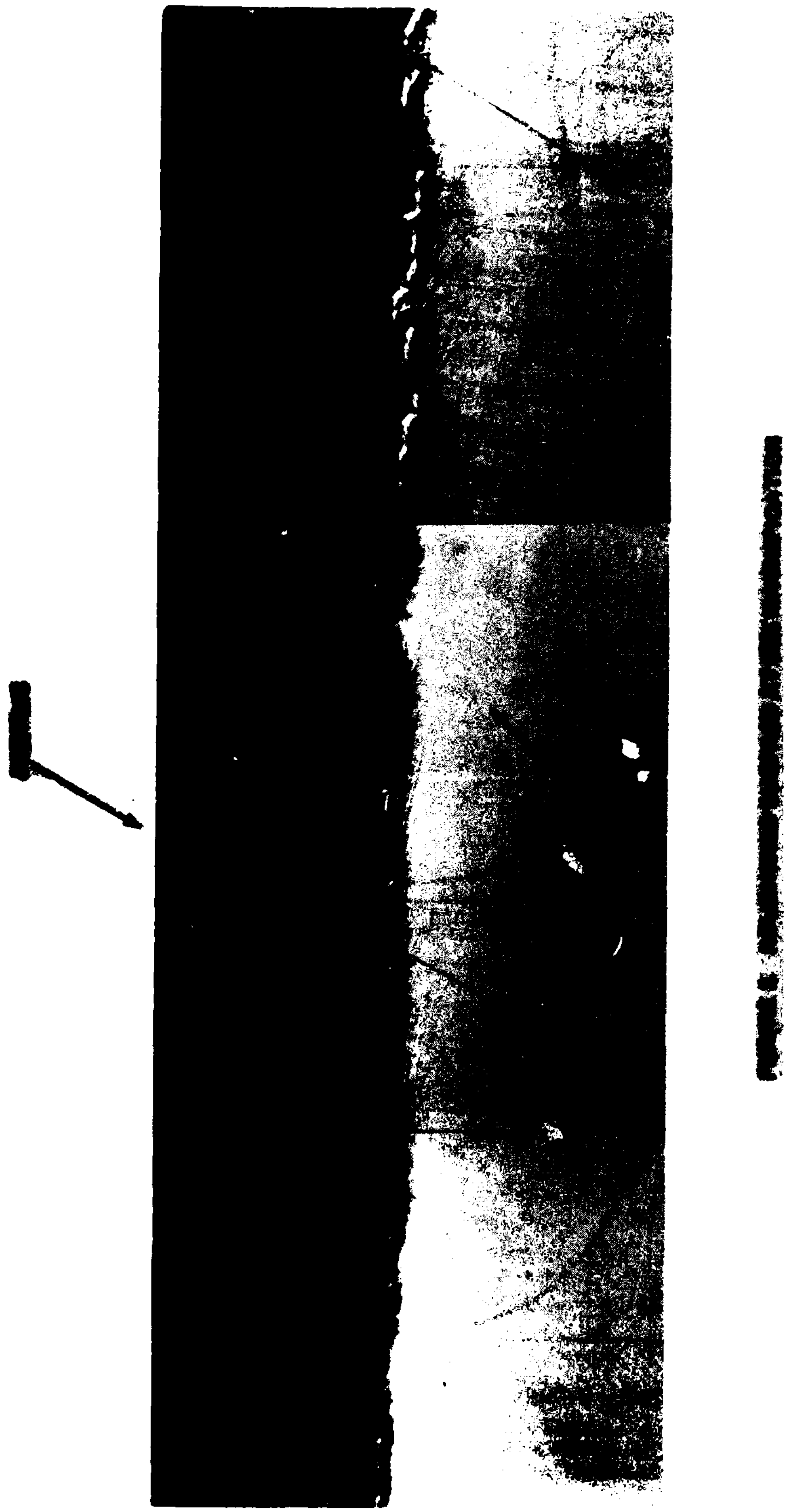
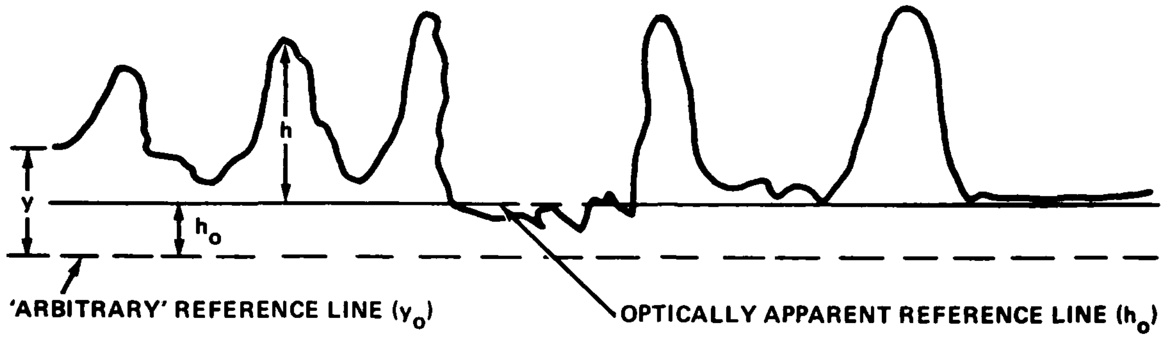


FIGURE 2. SAMPLE BEFORE AND AFTER GRIT BLASTING, SETTING IN ACRYLIC, AND SAMPLE HOLDER





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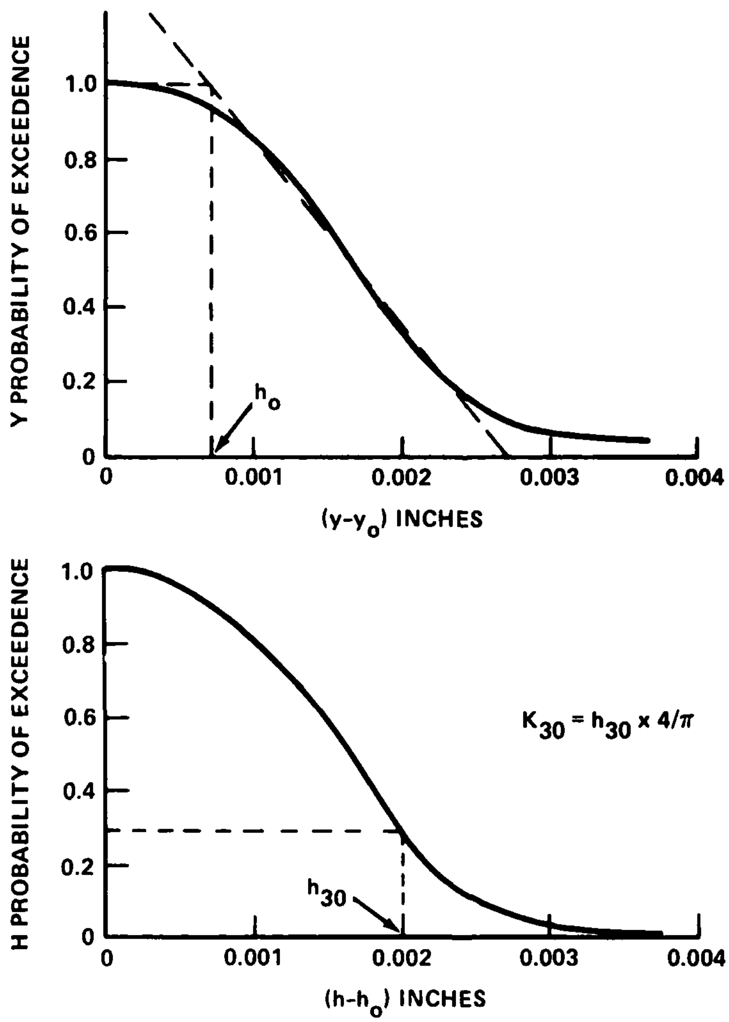


(b)

FIGURE 4. SURFACE ROUGHNESS CHARACTERIZATION AND DEFINITION

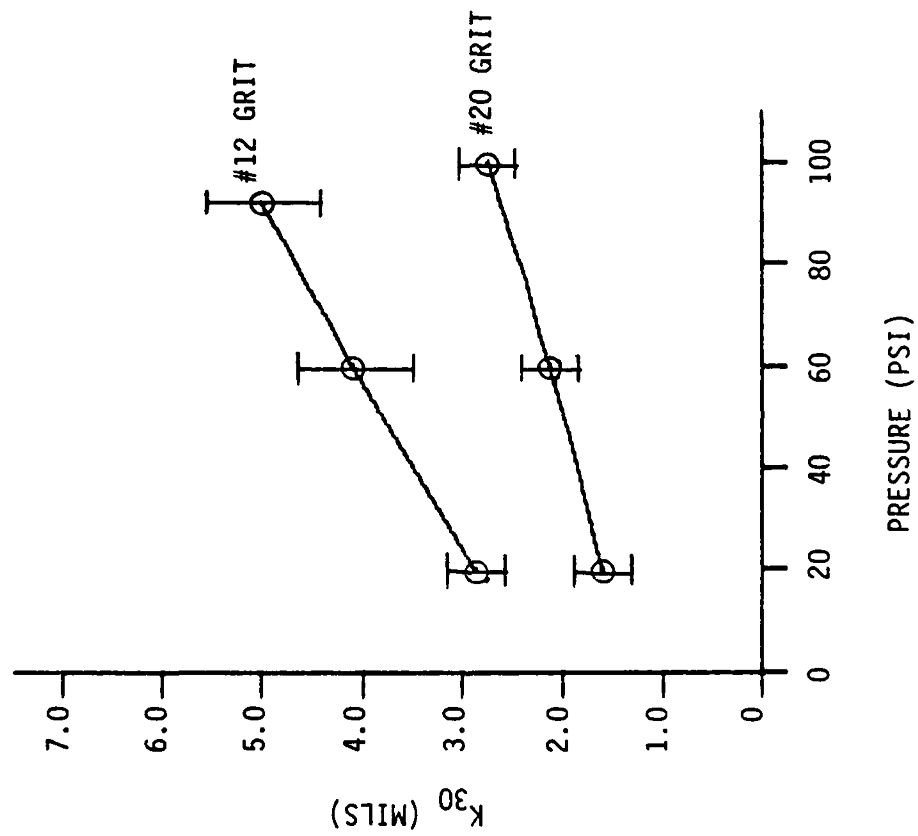
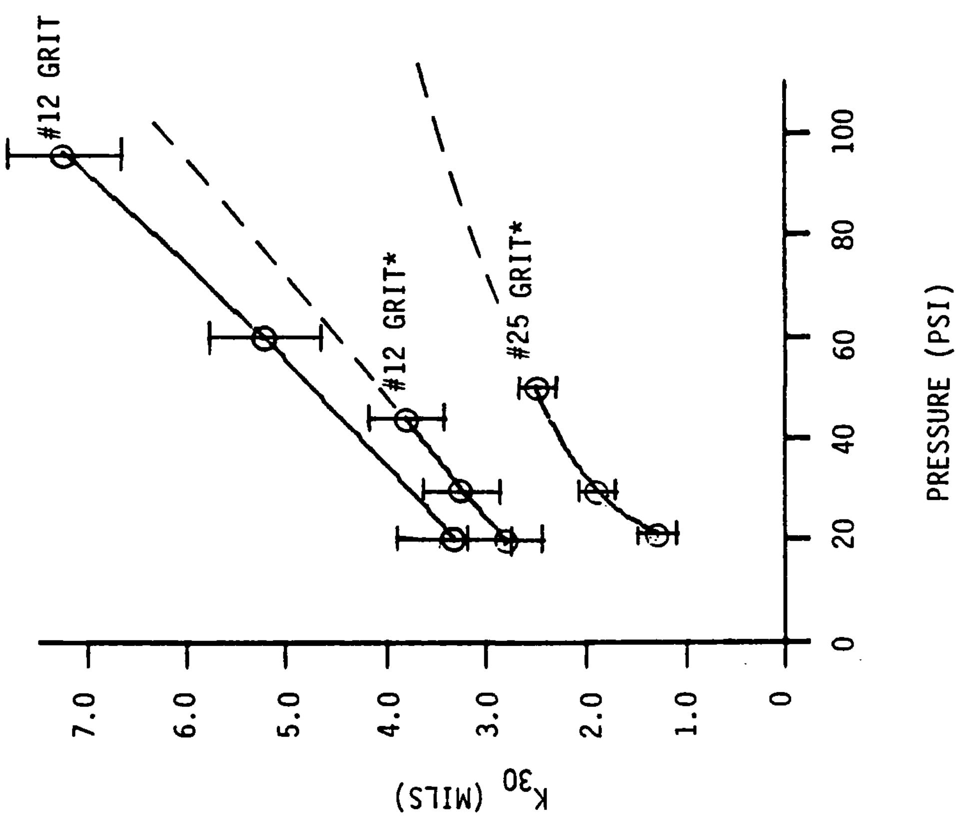


FIGURE 5. STAINLESS STEEL 17-4PH CALIBRATION CURVES



* Data points from AVCO MTSCT Tunnel 8 Program
(WTR 1346) NSWC MP 81-259

FIGURE 6. NICKEL 200 CALIBRATION CURVES

TABLE 1. STUDY SAMPLE DESCRIPTIONS

Sample #	Metal Type	Pressure (psi)	Grit Size	K_{30} Roughness Value (mils)	Magnification Factor
1	SS-17-4PH	20	12	2.88	100
2	SS-17-4PH	60	12	4.10	50
3	SS-17-4PH	92	12	4.98	50
4	SS-1150	20	20	1.60	100
5	SS-1150	60	20	2.13	100
6	SS-1150	100	20	2.75	100
7	N-200	20	12	3.32	50
8	N-200	60	12	5.23	50
9	N-200	96	12	6.74	50

Metal Type Abbreviations:

Stainless Steel 17-4PH--------------------SS-17-4PH
(annealed)
Stainless Steel 17-4PH--------------------SS-1150
(heat treated to 1150°F)
Nickel 200--------------------------------N-200
(annealed)

TABLE 2. COMPARISONS OF AVERAGE, ROOT MEAN SQUARED, AND 0.3 PROBABILITY ROUGHNESS VALUES

Sample #	Metal Type*	Pressure (psi)	Roughness Value (mils)** Average	Root Mean Square	0.3 Probability
1	SS-17-4PH	20	1.79	1.91	2.26
2	SS-17-4PH	60	2.53	2.80	3.22
3	SS-17-4PH	92	3.40	3.64	3.91
4	SS-1150	20	0.97	1.09	1.26
5	SS-1150	60	1.35	1.46	1.67
6	SS-1150	100	1.73	1.90	2.16
7	N-200	20	2.03	2.19	2.61
8	N-200	60	3.31	3.60	4.11
9	N-200	96	4.32	4.67	5.29

*See Table 1 for Metal Type abbreviations
**Values not multiplied by $4/\pi$ shape factor

TABLE 3. METAL HARDNESS NUMBERS

Metal Type	Hardness Number (Brinell)
Stainless steel 17-4PH annealed	332*
Stainless steel 17-4PH heat treated to 1150°F	311*
Nickel 200 annealed	110**

*Properties given by Republic Steel Corporation, Cleveland, Ohio 44101

**Materials Engineering, Materials Selector Issue, Vol. 66, No. 5, Mid-October 1967, p. 156 and Standard Handbook for Mechanical Engineers, Seventh Edition, McGraw-Hill Book Company, pp. 5-17.

APPENDIX A

RECOMMENDATIONS AND DATA

This section discusses improvements to the method used to characterize the surface roughness. These recommendations are included in order to reduce error sources in the future.

The magnitude of the error found depends largely on the magnification at which the photomicrographs are taken. The greater the magnification, the easier it is to measure surface heights, select significant peaks, and obtain a more accurate surface roughness value. When comparing the cost of analysis and preparing the photomicrographs to the accuracy desired, a maximum magnification of 250X is suggested.

Another consideration is edge retention. When a harder metal is surface roughened, it is suggested that a Bakelite method be used to encase the sample edge. This includes using pressure and heat when preparing the sample to be polished.

When drawing the y_o line, it has been found that a razor blade line is much finer and allows the zero on the eyepiece to be located more accurately. This procedure was implemented prior to the AVCO MTSCT Tunnel 8 test (WTR 1340) and accounts for the additional data points in Figure 6. The bias between the two calibration curves for the #12 grit in Figure 6 was due to the method of placing the y_o line on the photomicrographs. Note that the later calibration curves have been extrapolated to larger roughness values. The criteria to use for determining interval spacing on a set of photomicrographs is that a minimum of 100 data points be used for determining both the h_o and h_{30} values.

By implementing these recommendations, it is felt that the error bound for 50X and 100X magnification can be reduced to $\pm$ 0.4 mils and $\pm$ 0.2 mils respectively. The use of 250X magnification further reduces the error bound to $\pm$ 0.08 mils.

The figures that follow (Figures A-1 through A-9) are the results of the work documented earlier in this report. Each figure is comprised of four graphs designated as A, B, C, or D. In each case graph A is the y-yo histogram plot, graph B is the probability of exceedence vs. the y-yo curve generated for each test sample, graph C is the corresponding $h-h_o$ histogram plot, and graph D is the probability of exceedence vs. the $h-h_o$ curve.

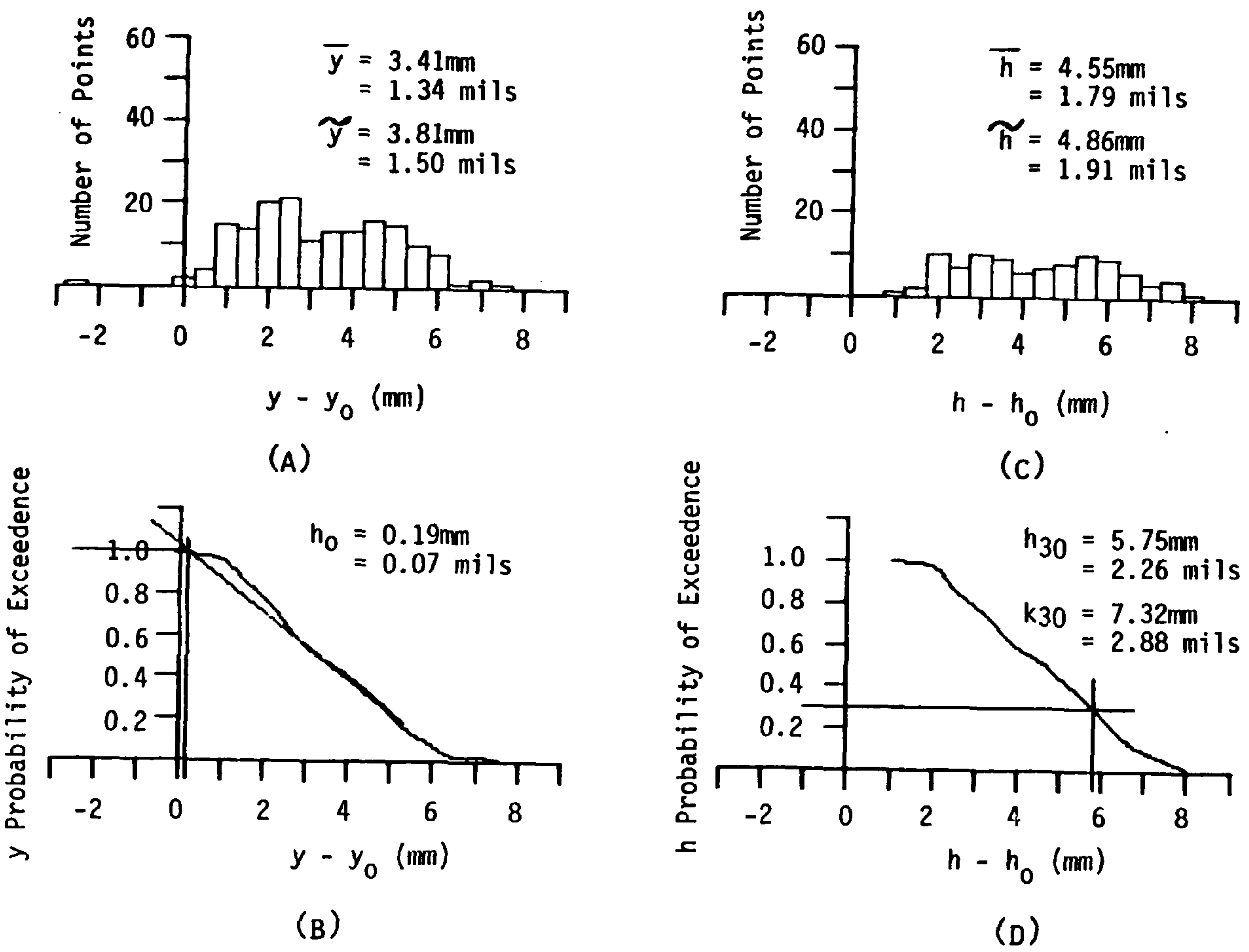


FIGURE A-1. STAINLESS STEEL 17-4PH, 20 PSI, #12 GRIT

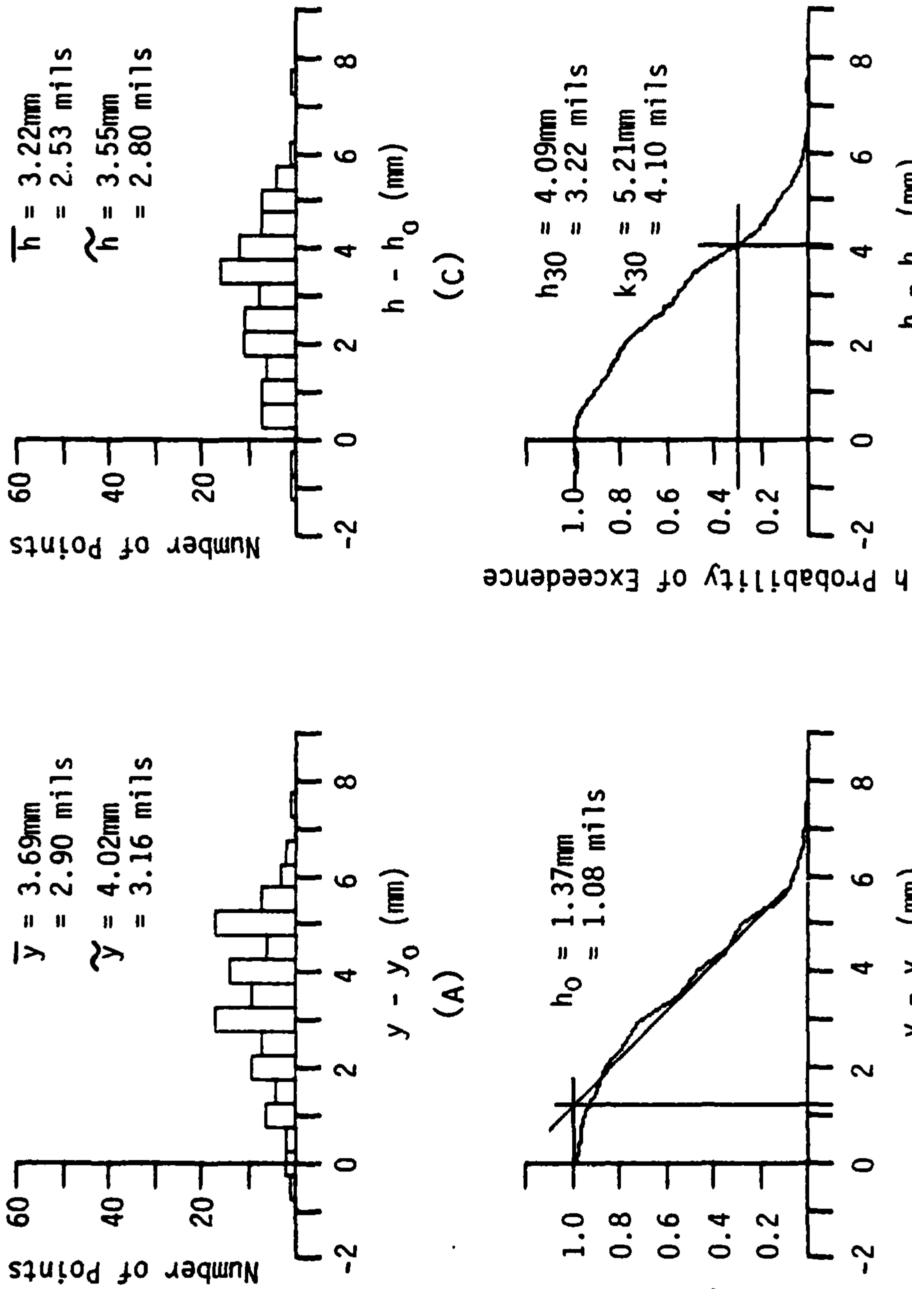


FIGURE A-2. STAINLESS STEEL 17-4PH, 60 PSI, #12 GRIT

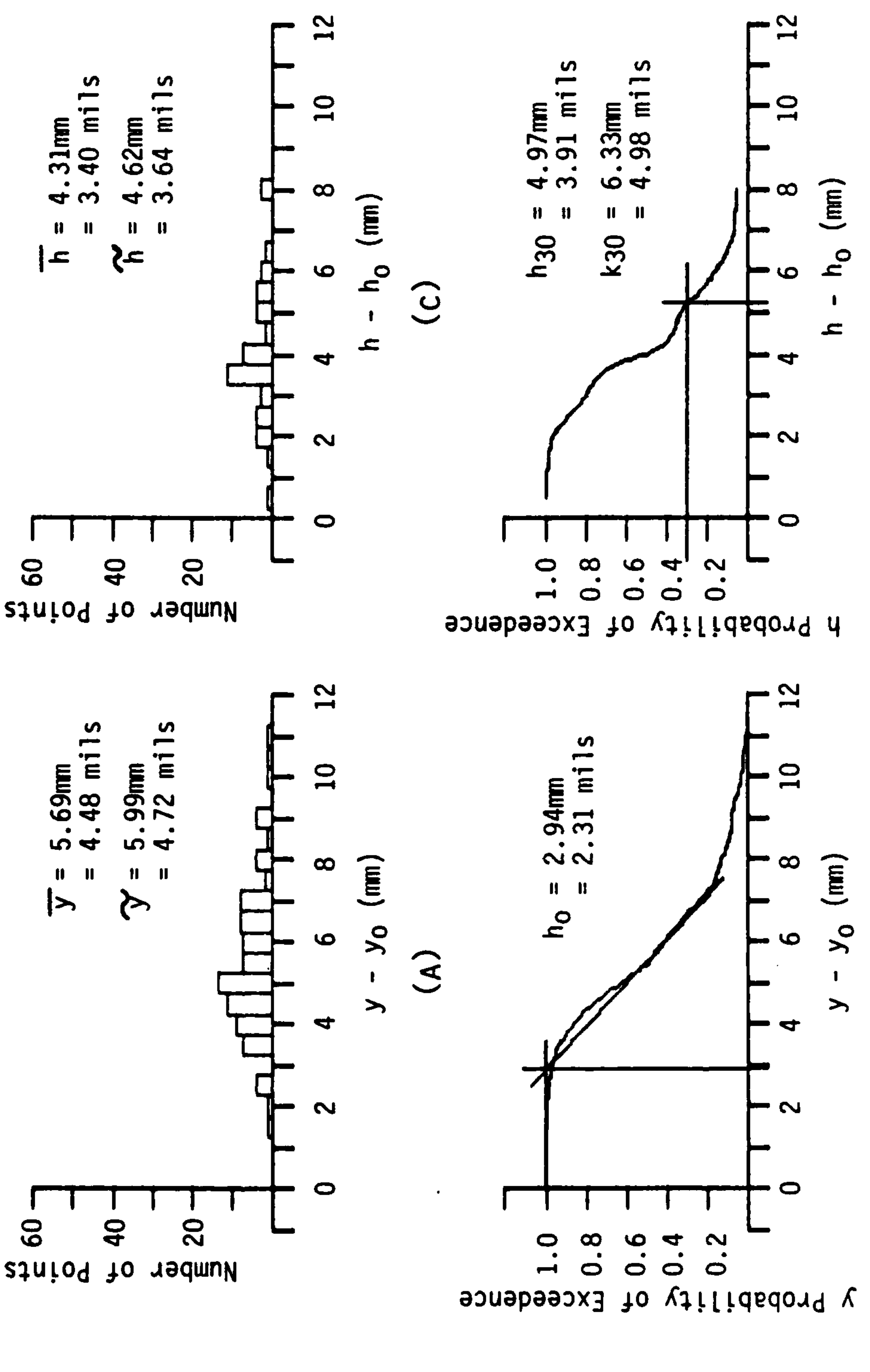


FIGURE A-3. STAINLESS STEEL 17-4PH, 92 PSI, #12 GRIT

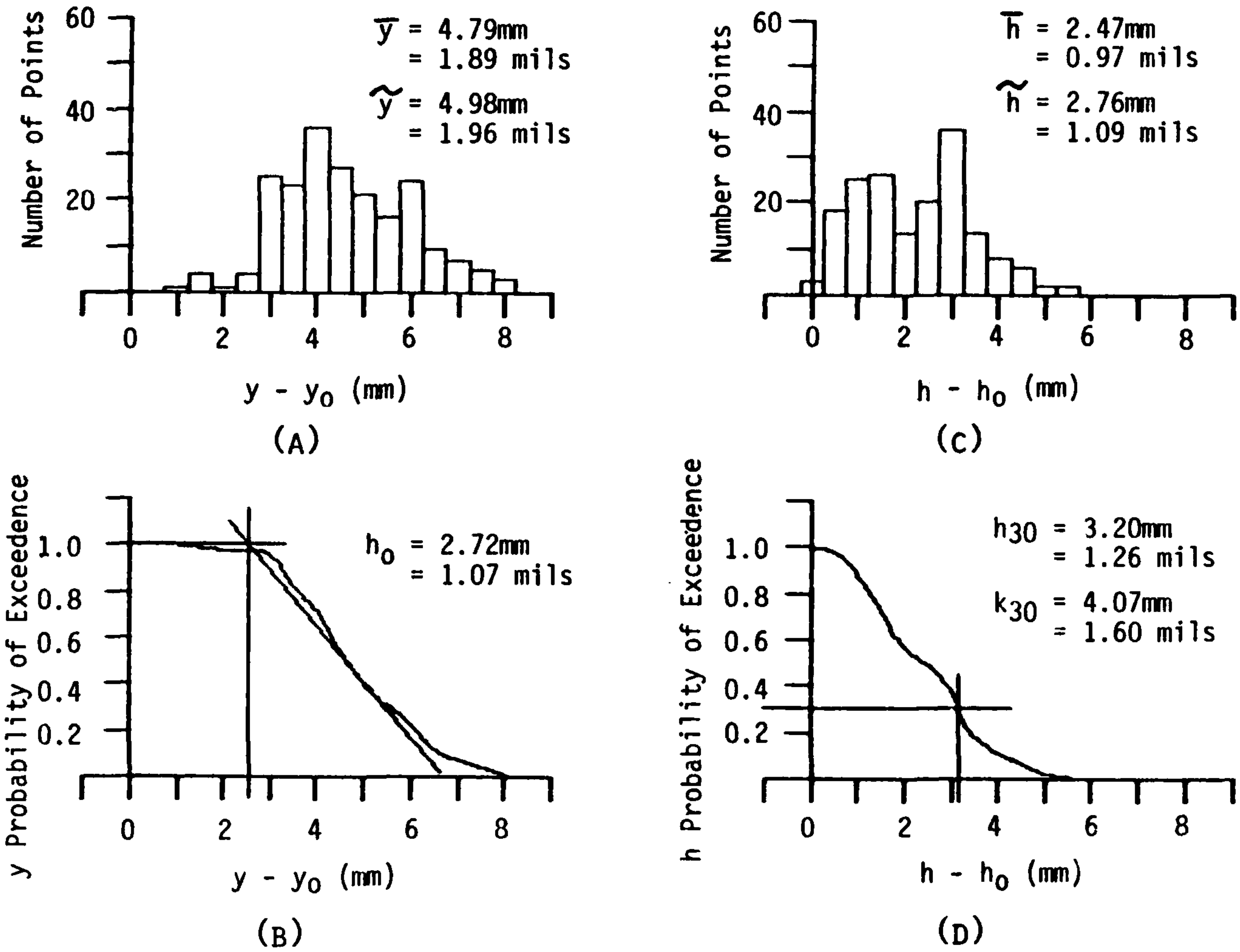


FIGURE A-4. STAINLESS STEEL 17-4PH HEAT TREATED TO 1150^{o}F, 20 PSI, #20 GRIT

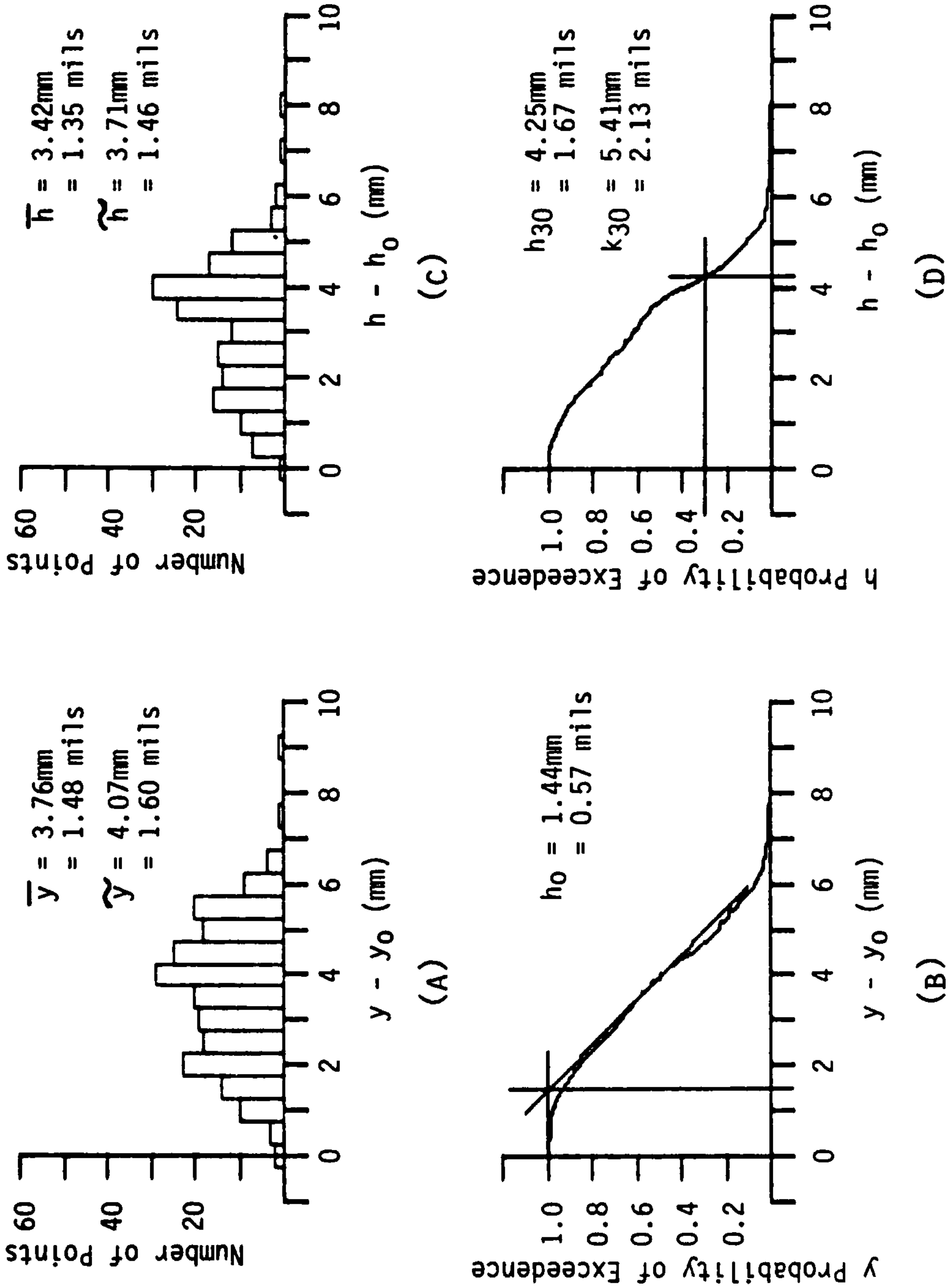


FIGURE A-5. STAINLESS STEEL 17-4PH HEAT TREATED TO 1150^{o}F, 60 PSI, #20 GRIT

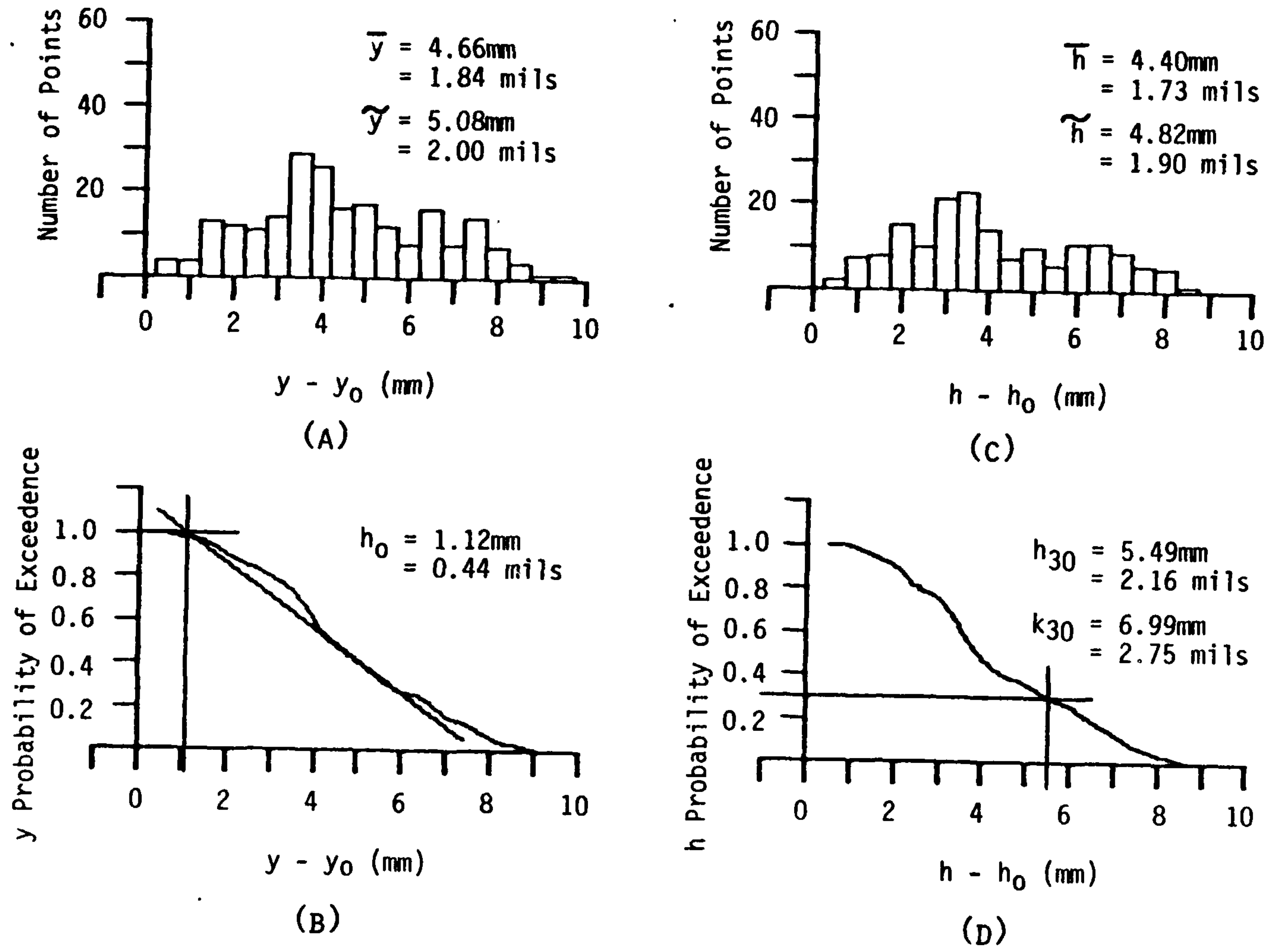


FIGURE A-6. STAINLESS STEEL 17-4PH HEAT TREATED TO 1150^{o}F, 100 PSI, #20 GRIT

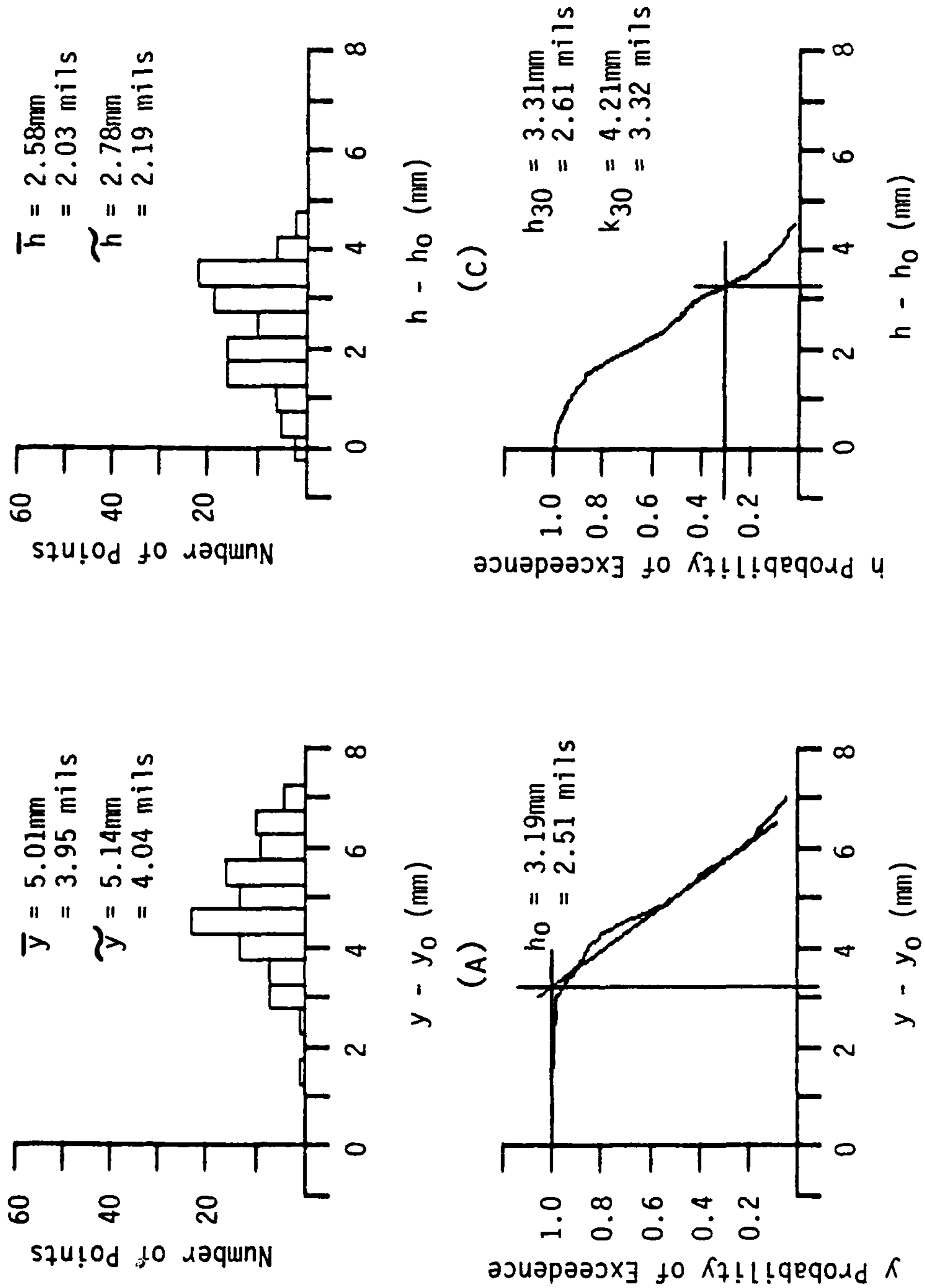


FIGURE A-7. NICKEL 200, 20 PSI, #12 GRIT

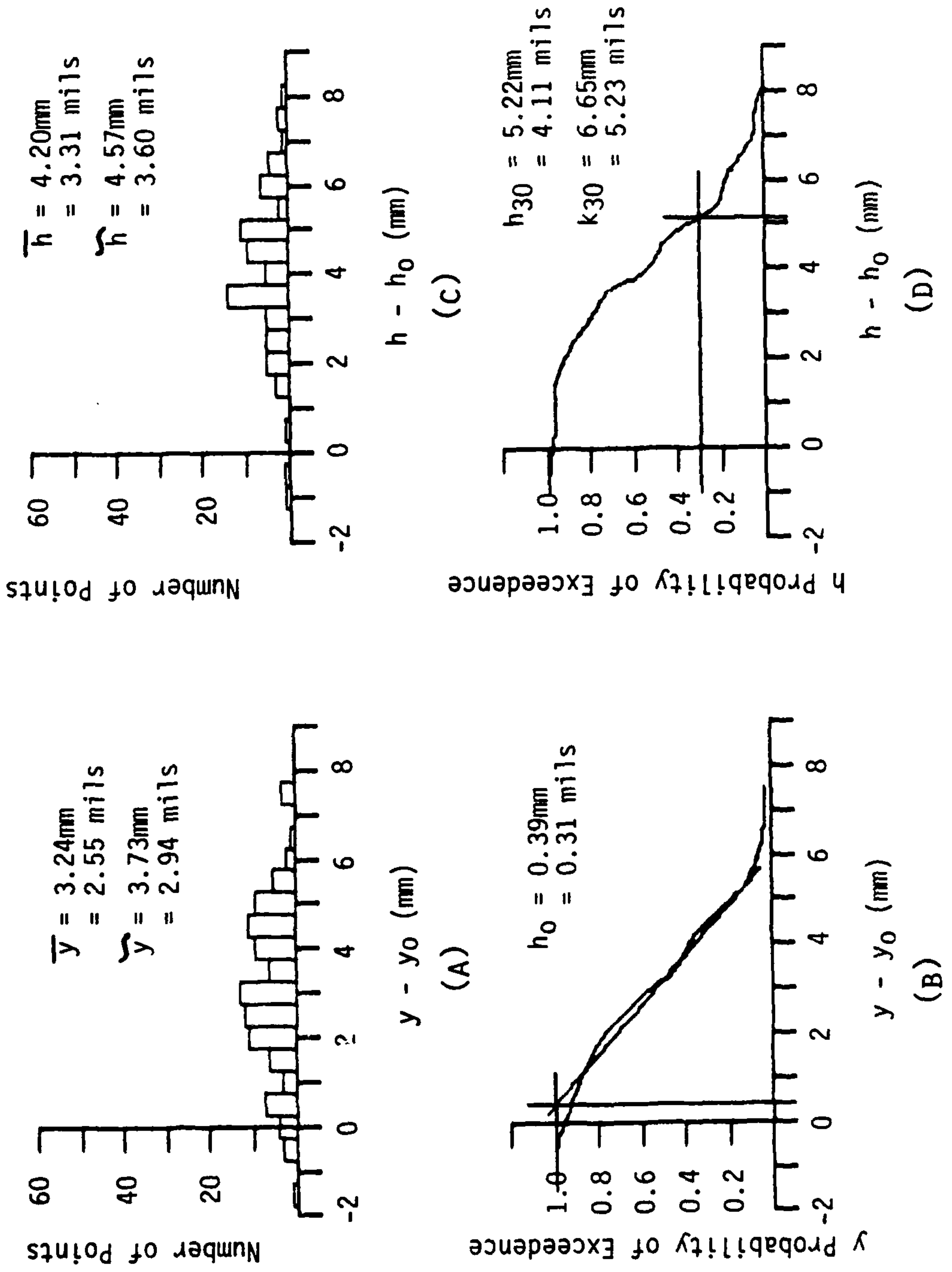


FIGURE A-8. NICKEL 200, 60 PSI, #12 GRIT

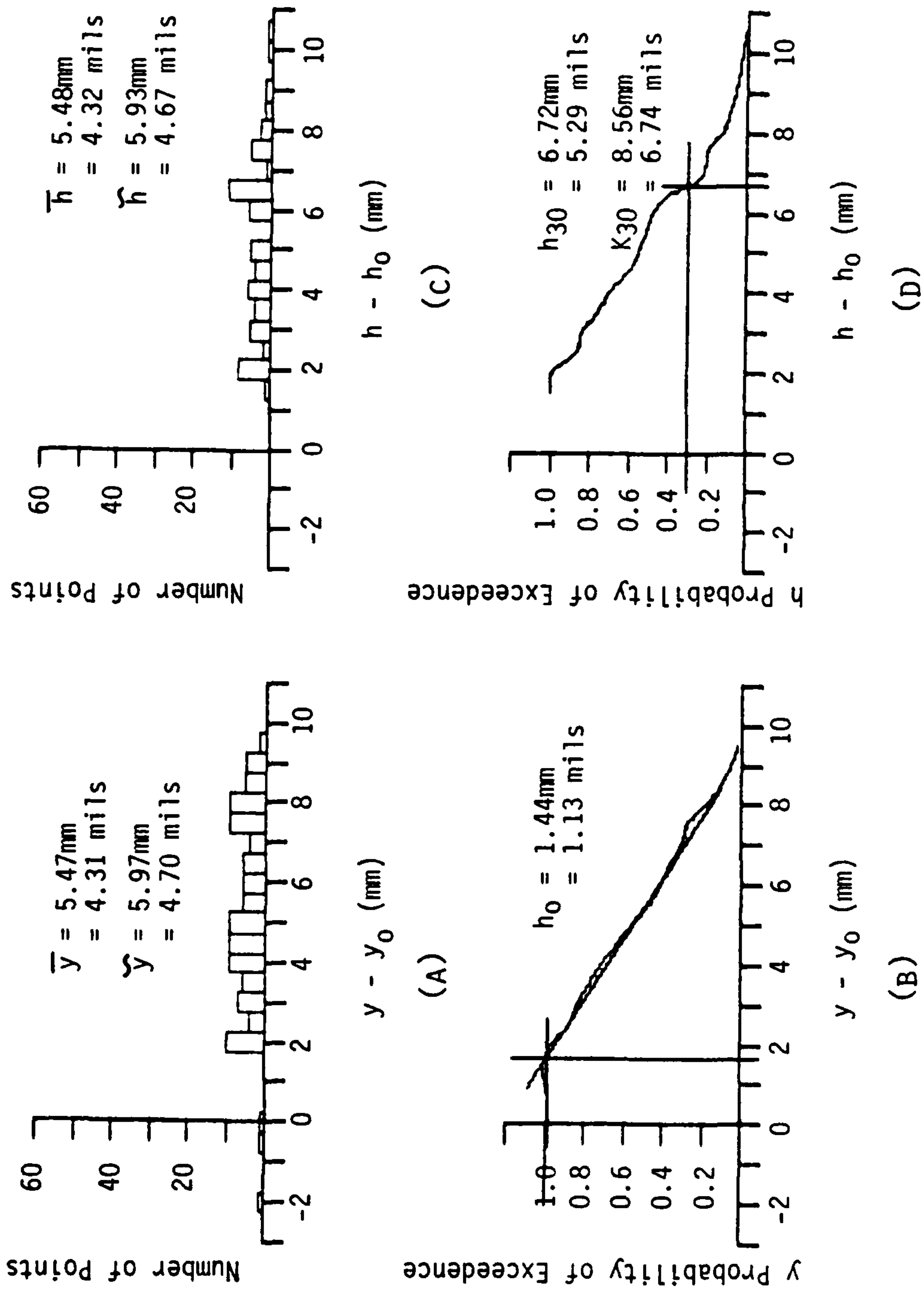


FIGURE A-9. NICKEL 200, 96 PSI, #12 GRIT

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